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Integrating AHP and VIKOR for Optimal Selection of Value Engineering Models in Mining Industry

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Abstract:
The steel industry is essential for national development, economic growth, infrastructure projects, technological advancements, and social welfare. However, these industries face significant challenges, including project delays, equipment breakdowns, quality fluctuations, and environmental issues. Addressing such challenges requires an effective managerial optimization method such as Value Engineering (VE). Therefore, this study conducts a comprehensive review of VE methods found in international standards and prior research, aiming to select the most appropriate model for an iron and steel company (ISC). The research adopts a mixed-methods approach, combining qualitative library studies with quantitative analysis using Multiple-Criteria Decision-Making techniques—specifically, the Analytical Hierarchy Process (AHP) and VIKOR. AHP results show that the "ability to rank and prioritize ideas" (weight = 0.309) and the "determination of evaluation criteria" (weight = 0.294) were the most critical factors in the evaluation. Based on these weights, the VIKOR method was employed to rank VE models, identifying the SAVE standard (Q = 0.0000) and the ASTM standard (Q = 0.076) as the most suitable for ISC. This study demonstrates that integrating AHP and VIKOR provides a reliable and adaptable approach for selecting VE models, ultimately supporting the iron and steel industry's goals for improved economic performance and environmental sustainability.
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1. Introduction

Engineering disciplines continue to evolve rapidly, with growing emphasis on optimization and advanced decision-making methods to address complex industrial challenges. Recent studies reflect this trend, exploring a range of applications from sustainable soil improvement using MICP [1] to structural damage detection via artificial neural networks [2], and analytical modeling in electronic engineering [3]. This emphasis on innovation directly supports critical industries such as steel manufacturing, which plays a foundational role in national economic development. Steel underpins infrastructure projects—including roads, bridges, and buildings—facilitating urbanization and modernization. In transportation, it is vital for the production of vehicles, rail systems, and maritime vessels, ensuring the efficient movement of people and goods. Additionally, the steel industry attracts significant investment, fosters job creation, and enhances a country's global competitiveness through export activity. By refining VE model selection tailored to this sector, the current research contributes to achieving greater efficiency, sustainability, and strategic growth in the steel industry [4–5].

In addition to the mentioned importance, steel industries also face challenges, including project delays or complete failures, production halts due to equipment breakdowns, product quality fluctuations affecting sales, and environmental pollution, such as air quality degradation, land erosion, damage to agricultural lands, and threats to human health near industrial facilities. Such issues result in financial losses and adverse health impacts. Addressing these challenges requires a managerial optimization method that enhances efficiency and sustainability within industries like steel production. By systematically identifying and eliminating unnecessary costs while maintaining or improving functionality, Value engineering (VE) fosters innovation and streamlines operations. In capital-intensive industries such as steel, where resource utilization and operational efficiency significantly impact profitability and environmental sustainability, the adoption of such methods ensures competitive advantage. Moreover, these

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strategies align with global trends toward cost-effectiveness and sustainable development, highlighting their importance for economic and ecological progress [6-8]. VE employs a systematic, step-by-step process to identify and assess the functional value of products, services, or projects. It then focuses on optimizing functions that require improvement while minimizing associated costs [9]. A key feature of this approach is its emphasis on functionality, which addresses multifaceted challenges by enabling modifications and enhancements without compromising production efficiency, profitability, or established processes. Additionally, VE fosters collaborative teamwork by integrating experts from diverse specialized fields. This collaborative approach ensures the effective harnessing of expertise across various domains, ultimately leading to the successful resolution of industrial challenges [6].

Therefore, this study conducts a comprehensive review of VE methods in standards and research and selects an appropriate model for an iron and steel company. The primary contributions of this research are: (1) to introduce the VE methodology and its defining characteristics, (2) to conduct a thorough analysis and synthesis of VE models presented in various standards and prior studies, and (3) to prioritize these models based on their suitability for the specific requirements of an iron and steel company, employing the VIKOR method, a multi-criteria decision-making approach designed for complex evaluations. From a managerial perspective, this research offers a strategic approach for enhancing decision-making processes, resource allocation, and strengthening interdisciplinary collaboration within the iron and steel company. By implementing VE models, managers can drive operational efficiencies and foster a culture of continuous improvement and innovation. This investigation represents a significant step toward providing a systematic review of VE models. While a prior study by Asgari [10] employed the TOPSIS method for VE standard ranking, the present study utilizes the VIKOR method, and an in-depth explanation of its advantages and decision-making rationale will be provided.

1.1. Case study

The steel factory under investigation represents a cornerstone of national economic stability and growth. As a pivotal player in the mining industry, the factory's operations have a profound impact on the country's profitability and industrial output. However, it faces significant challenges in process optimization, mitigating environmental impacts, and managing financial constraints. These multifaceted issues not only threaten the factory's efficiency but also its sustainability and contribution to the economy. Thus, comprehensive research to address these challenges is essential.

This research introduces a novel approach by integrating the Analytical Hierarchy Process (AHP) and VIKOR methods to identify the most effective VE models for the factory's unique needs. The combination of AHP and VIKOR, while innovative, has not been extensively explored in the steel industry, making this study unique. VE, a systematic approach aimed at enhancing the value of products and processes, provides a viable solution to the factory's challenges. By integrating AHP and VIKOR, resources can be allocated efficiently to yield the highest benefits, ensuring a structured framework for improvement initiatives.

The significance of this research extends beyond the steel factory itself. Findings can serve as a model for other enterprises in the mining industry, offering valuable insights into the application of AHP and VIKOR for optimal VE. This study also addresses gaps in the literature by providing a comprehensive evaluation of VE models specifically tailored to the mining sector. Such insights can contribute to industry-wide improvements, promoting sustainability, efficiency, and profitability on a larger scale. The integration of these advanced management techniques can help other factories overcome similar challenges, contributing to a more resilient industrial sector.

In conclusion, this research has the potential to transform the steel factory's operations and the broader mining industry. By introducing the combined application of AHP and VIKOR, the study highlights an innovative approach to VE that can lead to significant advancements in process optimization, environmental impact reduction, and financial management. The necessity of adopting such innovative management methods lies in navigating the complexities of modern industrial operations. This research holds the promise of enhancing the factory's performance and sustainability, making it a critical contribution to the industry.

The subsequent sections of this research are meticulously structured to facilitate a comprehensive understanding of the VE methodology and its application within the case study of the iron and steel company. Section 2 delves into the core principles of VE, providing a critical review of the models presented in established standards and documented within various research studies. Section 3 establishes the theoretical foundation for the employed decision-making framework, introducing Multiple-Criteria Decision Making (MCDM) methods, specifically focusing on the AHP and the VIKOR method. Section 4 utilizes the AHP method to determine the relative weights assigned to the established evaluation criteria. Subsequently, this section employs the VIKOR method to systematically rank the VE models based on their suitability for the iron and steel company. Finally, Section 5 concludes the research by presenting the meticulously obtained results.

2. Literature review

2.1. Value Engineering (VE)

As elaborated previously, VE constitutes a management methodology applicable to a broad spectrum of industrial challenges. A hallmark of this approach lies in its emphasis on teamwork, fostering a creative and functional environment to eliminate, modify, or substitute factors that influence the value proposition of a product, process, or project [6]. VE fulfils a dual purpose: maximizing value and concurrently resolving technical and managerial problems encountered within industrial operations [11]. The distinctive characteristic of this method resides in its function-centric approach. Product or process functions are defined as the synergistic combination of an active verb and a quantifiable noun. By systematically identifying and analysing these functions, VE unveils opportunities for advancements and improvements [12]. Furthermore, VE offers a multitude of advantages, including cost reduction, enhanced quality management practices, streamlined procedures, increased operational efficiency, optimized production expenditures, cultivating a value-oriented mindset within the workforce, and ultimately achieving superior market competitiveness [13].

The job plan of VE typically consists of three stages: pre-study, study, and post-study [14]. Each of these stages plays a crucial role in ensuring that the project achieves optimal value through systematic evaluation and improvement. The study stage comprises the following six steps [15]:

1. **Pre-study:** This initial phase is focused on gathering baseline data and setting the foundation for the VE process. It involves understanding the project's objectives, constraints, and stakeholder needs. The pre-study ensures that all relevant information is collected, including project goals, budget, and timeframes. During this phase, the team also identifies the key functions that will be analysed later. The pre-study phase prepares the team for the study stage by clarifying the scope and setting clear performance targets.

2. **Study:** The study phase is where the core VE activities take place. This stage is composed of six steps [15]:

- **Information**: Gathering the necessary information to present results based on the project objectives and scope.
- **Function Analysis**: Defining project functions to determine which ones need improvement, elimination, or creation to achieve project goals.
- **Creativity**: Utilizing creative techniques to identify better approaches for performing project functions.
- **Evaluation**: Assessing ideas to determine which ones, considering implementation requirements and resource constraints, lead to value improvement.
- **Development**: Selected ideas are turned into documented scenarios, enabling decision-makers to evaluate the proposed option.
- **Presentation**: The final report, including proposed options, is presented to decision-makers.

3. **Post-study:** After the study phase, the post-study stage involves reviewing the outcomes of the VE process and implementing the recommended changes. This phase focuses on assessing the success of the selected alternatives and ensuring that they align with the project's objectives and requirements. The post-study stage often includes a follow-up evaluation to measure the actual performance and value achieved compared to the initial expectations. Adjustments or refinements may be made during this stage to ensure that the project delivers the best value.

2.2. References and standards of VE

An extensive examination of the extant literature unveils a multifaceted landscape of VE work plans proffered by both domain experts and standardized methodologies. These discrepancies arise from the intrinsic characteristics of the investigated subject matter and the unique configuration of the VE program employed within a specific organization or project [10]. Some of the references and standards are introduced in Table 1.

Table 1. References and standards of VE

Reference/Standard	Title	Steps	Some features
Lawrence D. Miles [16]	Techniques Of Value Analysis And Engineering	1. Information 2. Analysis 3. Creativity 4. Judgment 5. Development planning	• Uncomplicated and simple to implement
American Society of Testing and Materials [15]	Value Standard And Body Of Knowledge	1. Pre-workshop/study 2. Workshop/Study 2.1. Information 2.2. Functional analysis 2.3. Creative 2-4. Evaluation 2.5. Development 2.6. Presentation 3. Post workshop/study 3.1. Implementation 3.2. Follow-up	• Comprehensiveness of the model • Paying attention to forming a team, determining the scope of study, and obtaining information • Determination of evaluation criteria • Having recommendations to do the phases better • Follow up on work results
American Society of Testing and Materials [17]	Standard Practice for Performing Value Analysis (VA) of Buildings and Building Systems	1. Preparation effort 1.1. Project coordination 1.2. Preparation for the workshop 1.3. Creating cost models, life cycle cost, energy 2. Workshop effort 2.1. Information 2.2. Function identification and analysis 2.3. Creative 2.4. Evaluation 2.5. Development 2.6. Presentation 3. Post-workshop effort 3.1. Implementation 3.2. Final Acceptance	• Comprehensiveness of the model • Consider team building • Suitable for projects • Consider costs • Having recommendations to do the phases better • Implementation of study results
European Standard [18]	Value Management	0. Preliminary steps 1. Project definition 2. Planning	• Comprehensiveness and complexity • Risk analysis • Suitable for projects

		3. Gathering comprehensive data about the study 4. Functional analysis, cost analysis, and detailed objectives 5. Gathering and creating solution ideas 6. Evaluation of solution ideas 7. Development of proposals 8. Presentation of the proposals 9. Implementation	• Consider team-making and study timing • Market research • Having recommendations to do the phases better • Time-consuming model implementation • Implementation and follow-up of results
Australian Standard [16]	Value Management	1. Pre-workshop planning 1.1. Prepare/review value management brief 1.2. Select study group members 1.3. Organize a venue 1.4. Gather and distribute relevant information 1.5. Prepare facilitation strategy and agenda 1.6. Brief Study group members 2. Workshop 2.1. Confirm Study objectives 2.2. Confirm scope 2.3. Build knowledge 2.4. Generate multiple ideas 2.5. Evaluation 2.6. Development 2.7. Recommendations 2.8. Prepare an action plan 3. Post workshop 3.1. Post study	• Comprehensiveness and complexity • Comprehensive consideration of model prerequisites • The importance of forming a team, setting goals and scope, costs • Determination of evaluation criteria • Time-consuming model implementation • Implementation and follow-up of results

2.3. VE in research

Numerous scholarly endeavors have introduced VE models, frequently incorporating adaptations to the constituent stages, leveraging the aforementioned reference materials and established standards (Table 2).

Table 2. Goals and steps of VE in articles

References	Goal/Subject	Methodology
[20]	Improving product design, reducing costs, and increasing customer satisfaction	• SAVE standard
[21]	Irrigation and drainage networks project	• Pre-study • Information • Functional analysis • Identify areas of improvement • Co-thinking and creativity • Additional activities • Presentation
[22]	Improving project performance	• SAVE standard
[23]	Research in the field of medical equipment	• SAVE standard
[24]	A developed model considering production processes and the supply chain network	• Planning • Data collection • Functional analysis • Creativity • Evaluation • Development • Presentation • Implementation
[25]	Speeding up actions in urban planning	• SAVE standard
[26]	Development of innovative high-speed bus transportation systems	• SAVE standard
[27]	The project of an international hospital	• Primary • Information • Creativity • Evaluation • Implementation
[28]	Analysis of different humidifier components	• Information • Functional analysis • Creativity

		• Evaluation • Proposal • Implementation
[29]	Reducing the cost and improving the value of chassis components in heavy vehicles	• General phase: Establishing the work of VE • Information phase: Gathering information • Functional phase: Identification of inconsistent values • Creativity phase: Producing a large number of solutions • Evaluation phase: Determining options with higher potential • Inspection phase: Development of actionable proposals • Proposal phase: Action on proposals
[30]	Research on the academic environment	• Pre-study • Planning the value study • Organization of value study • Study • Information • Functional analysis • Creativity • Evaluation • Development • Presentation • Post-study • Implementation • Follow-up
[31]	Improvement and implementation of the tunnelling project	• Primary study • Information step • Study during implementation • Function analysis • Plan optimization • Evaluation and monitoring • Post-study • Development • Implementation
[9]	The effect of drainage covers on the environment	• SAVE standard
[13]	Reducing the costs of the furniture industry	• Analysis of information • Analysis of the workshop plan • Process flow chart • Functional analysis • Preparation of numerical evaluation papers • Creativity sheet • Evaluation phase • Proposal phase
[32]	Energy optimization project	• Information • Functional analysis • Creativity • Evaluation • Development of proposals • Presentation of reports
[33]	Designing sustainable and energy-efficient buildings	• Acquaintance • Information • Functional analysis • Creativity • Evaluation • Development • Presentation • Implementation
[8]	Dust reduction in mining industries	• SAVE standard
[34]	Investigating the effects of VE on the performance of interchanges	• Information • Function analysis • Creation • Evaluation • Development • Presentation
[35]	Presenting a quantitative and qualitative content analysis of the application of VE in construction projects	• Information • Functional analysis • Creativity • Evaluation • Development • Presentation
[36]	Maximize the utilization of the budget in the school building plan	• SAVE standard
[37]	Enhance project efficiency and cost-effectiveness in the construction industry	• SAVE standard
[38]	Determine the thermal insulation material to be used in a building	• Selection • Research

		• Theory-creating • Evaluation • Development • Presentation • Application • Check-in
[39]	Current state and application of value engineering in Egypt's construction industry	• SAVE standard
[40]	Automating the VE process for selecting pipe materials using a BIM framework	• FAST Diagram
[41]	Examine the role of VE and VA in supply chain optimization.	• Information • Functional analysis • Creativity • Evaluation • Development • Presentation
[42]	Promote VE’s role in efficiency and innovation.	• Information • Function Analysis • Creative • Evaluation • Development • Implementation.
[43]	Apply VE concepts to AI value alignment and ethics.	• Introduces customized value-based reasoning, adapting evaluation and value assessment stages.

2.4. Research Gap

A conspicuous trend within the research background is the predominant utilization of the SAVE standard across various studies. Conversely, some studies forgo explicit reference to a particular standard, opting to leverage established steps associated with the study stage. This observation highlights potential limitations in the research community's familiarity with, or access to, a more comprehensive array of VE standards. The literature review of this study aims to fill this gap by presenting VE methodologies in standards and studies. A meticulous analysis of the reviewed literature reveals that studies have achieved positive outcomes, such as cost reductions, through implementing VE. Additionally, some studies showcase the efficacy of a creative and team-centric VE approach, even in the absence of explicitly quantified results. Collectively, these findings underscore the effectiveness of the VE methodology and emphasize the potential for superior results through a deeper understanding of VE stages, steps, and established standards, coupled with rigorous implementation practices.

Although VE has been successfully applied in industries such as construction, manufacturing, and infrastructure, systematic comparisons of VE models specifically tailored to the mining and metallurgical sectors, especially within iron and steel companies (ISC), remain scarce. Moreover, while many studies employ isolated MCDM techniques such as AHP or TOPSIS, few have integrated these methods to evaluate and prioritize VE models based on the nuanced requirements of the mining industry.

Furthermore, many existing studies either overlook newer VE standards or rely on traditional approaches without validating their adaptability to evolving industrial conditions, including environmental sustainability, production efficiency, and equipment reliability. There is also a gap in incorporating up-to-date research from 2024–2025, which reflects recent innovations in VE practices and decision-support systems.

3. Methodology

Granular computing is an emerging paradigm in information processing that deals with data abstraction and processing at various levels of granularity [44]. This concept is inspired by the way humans naturally process information at different levels of detail, focusing on the structure and dynamics of information granules.

In this study, the MCDM method, a subset of Operations Research, is employed as a managerial decision-making tool. MCDM models are categorized into two main groups [6]:

- Multiple Objective Decision Making (MODM) for optimizing design problems.
- Multiple Attribute Decision Making (MADM) for selecting the best alternative.

In the current research, the AHP and VIKOR methods, both classified as MADM models, are utilized to weigh evaluation criteria and identify the optimal alternative. The application of AHP and VIKOR in assessing and prioritizing VE models exemplifies multi-criteria decision analysis (MCDA). This process can be enhanced by granular computing principles, such as hierarchical decomposition and granulation, multi-granularity analysis, and information fusion [45-46].

3.1. AHP Method

The AHP method is employed to determine the weights of evaluation criteria through pairwise comparisons. This method transforms qualitative assessments into quantitative values and is backed by strong mathematical logic [47]. The implementation steps are as follows:

1) Pairwise comparisons: Alternatives are compared two by two based on preference values, as shown in Table 3:

Table 3. Numerical scores of alternatives in pairwise comparisons

Preferences	Numerical value
Equal importance or desirability	1
Slightly more important or desirable	3
Strong importance or desirability	5
Very strong importance or desirability	7
Completely more important or desirable	9
Interval preferences	2, 4, 6, 8

$$D = \left(r_{ij}\right),\ i = 1, \dots, m\ ;\ j = 1, \dots, n^{2} \quad (1)$$

$$r_{ji} = \frac{1}{r_{ij}} \quad (2)$$

3) Creation of normalized decision matrix (N_D): The N_D is obtained by dividing the elements of the D by the sum of the elements of the corresponding column (Equations 3 and 4).

$$N_D = \left(n_{ij}\right),\ i = 1, \dots, m\ ;\ j = 1, \dots, n \quad (3)$$

$$n_{ij} = r_{ij} / \sum_{i=1}^{m} r_{ij} \quad (4)$$

4) Calculation of the vector of relative weights (w): The $\boldsymbol{w}$ is formed by calculating the average of the rows of the $\boldsymbol{N_D}$ [Equations 5].

$$w_i = \left(\sum_{j=1}^{n} n_{ij}\right)/n \quad (5)$$

The AHP method also requires the calculation of the Incompatibility Ratio (IR). If the IR is greater than or equal to 0.1, it indicates incompatibility in the pairwise comparisons. The steps for computing the IR are as follows:

1) Calculation of the weighted sum vector (w_s): The $\boldsymbol{N_D}$ is multiplied by the $\boldsymbol{w}$ [Equation 6].

$$w_s = N_D \times w \quad (6)$$

2) Calculation of compatibility vector (c): The elements of the $\boldsymbol{w_s}$ are divided by the $\boldsymbol{w}$ [Equations 7 and 8].

$$c = (c_i) \quad (7)$$

$$c_i = w_{s_i} \div w_i \quad (8)$$

3) Obtaining the largest value of λ (λ_{max}): The largest eigenvalue is obtained by calculating the average of the elements of the $\boldsymbol{c}$ [Equation 9].

$$\lambda_{max} = \left(\sum_{i=1}^{m} c_i\right)/m \quad (9)$$

4) Calculation of incompatibility index (II): The $\boldsymbol{II}$ is obtained using Equation 10, where n is the number of alternatives.

$$II = (\lambda_{max} - n)/(n - 1) \quad (10)$$

5) Calculating the Random **Index (RI):** This index is obtained using Table 4 and n.

Table 4. the RI values

n	RI	n	RI
1	0	7	1.32
2	0	8	1.41
3	0.58	9	1.45
4	0.9	10	1.49
5	1.12	11	1.51
6	1.24	12	1.48

6) Calculation of Incompatibility Ratio (IR): The $\boldsymbol{IR}$ is obtained by dividing the $\boldsymbol{II}$ by the $\boldsymbol{RI}$ [Equation 11]. If the $\boldsymbol{IR}$ is 0.1 or greater, it indicates an inconsistency in the comparisons.

$$IR = II/RI \quad (11)$$

3.2. VIKOR Method

The VIKOR method is a multiple-criteria optimization technique suited for complex problems with conflicting criteria. This method ranks alternatives based on their initial criterion weights and selects the top-ranked alternative [48-49].

The VIKOR method is particularly valuable in the iron and steel industry, where decision-making involves multiple conflicting criteria such as cost efficiency, environmental impact, product quality, and operational efficiency. By identifying a compromise solution that balances these diverse criteria, the VIKOR method ensures that the selected solution minimizes regret and maximizes overall satisfaction. This is achieved by evaluating options based on their proximity to both the ideal and least favourable outcomes.

One key advantage of the VIKOR method in the iron and steel industry is its flexibility in handling both quantitative and qualitative criteria, essential in such a multifaceted sector. The systematic approach to ranking options based on relative performance ensures transparency and consistency in the decision-making process. Additionally, sensitivity analysis allows stakeholders to assess the robustness of the chosen solution, ensuring its effectiveness under varying conditions. Overall, the VIKOR method's emphasis on compromise solutions, adaptability to diverse criteria, and robust analytical framework makes it an ideal tool for informed and balanced decision-making in the iron and steel industry.

The steps for implementing the VIKOR method are summarized as follows [50-51]:

Step 1- Creation of decision matrix ($\boldsymbol{D}$): This matrix is formed by placing the alternatives to be ranked in the rows and the criteria in the columns [Equation ()]. In this matrix, if the criterion is quantitative, its actual value is assigned to the alternative, and if the criterion is qualitative, the alternatives would be evaluated as follows:

- **Positive qualitative criteria:** very low =1, Low =3, Medium= 5, Much =7, Very much= 9.
- **Negative qualitative criteria:** very low =9, Low 7, Medium= 5, Much =3, Very much=1.

$$\boldsymbol{D} = (r_{ij});\ i = 1, \dots, m, j = 1, \dots, n \tag{12}$$

Step 2- Calculation of the normalized decision matrix ($\boldsymbol{N_D}$): T This matrix is obtained by dividing the elements of the D matrix by the square roots of the sums of the corresponding column elements [Equations 13 and 14].

$$\boldsymbol{N_D} = (n_{ij});\ i = 1, \dots, m, j = 1, \dots, n \tag{13}$$

$$n_{ij} = r_{ij} / \sqrt{\sum_{i=1}^{m} r_{ij}^2} \tag{14}$$

Step 3- Calculation of the weighted normalized decision matrix ($\boldsymbol{F}$): This matrix is obtained by multiplying the $\boldsymbol{N_D}$ matrix by the weights matrix (M_w). M_w is a diagonal matrix, with the main diagonal elements representing the weights of the criteria ($\boldsymbol{w}$) [Equations 15 to 17].

$$\boldsymbol{w} = (w_j);\ j = 1, \dots, n \tag{15}$$

$$M_w = \begin{bmatrix} w_1 & 0 & 0 \\ 0 & w_2 & 0 \\ 0 & 0 & w_3 \end{bmatrix} \tag{16}$$

$$\boldsymbol{F} = (f_{ij}) = \boldsymbol{N_D} \times \boldsymbol{M_w};\ i = 1, \dots, m, j = 1, \dots, n \tag{17}$$

Step 4- Determining the best $\boldsymbol{f_j^*}$ and the worst $\boldsymbol{f_j^-}$: For positive criteria, f_j^* is the largest value in the corresponding column of the F matrix, and f_j^- is the smallest value in that column [Equation 18]. For negative criteria, f_j^* and f_j^- are obtained differently [Equation 19].

$$f_j^* = \max_i f_{ij}, f_j^- = \min_i f_{ij} \tag{18}$$

$$f_j^* = \min_i f_{ij}, f_j^- = \max_i f_{ij} \tag{19}$$

Step 5- Computing utility measure ($\boldsymbol{S_i}$) and regret measure ($\boldsymbol{R_i}$): The Utility (S_i) and Regret (R_i) measures are obtained from Equations 20 and 21)**.**

$$S_i = \sum_{j=1}^{n} w_j \times (f_j^* - f_{ij})/(f_j^* - f_j^-) \tag{20}$$

$$R_i = \max_j [w_j \times (f_j^* - f_{ij})/(f_j^* - f_j^-)] \tag{21}$$

Step 6- Computation of the VIKOR Index ($\boldsymbol{Q_i}$): The VIKOR Index is obtained from Equation 22.

$$Q_i = v \times (S_i - S^*)/(S^- - S^*) + (1 - v) \times (R_i - R^*)/(R^- - R^*) \tag{22}$$

Where:

$$S^* = \min_i S_i;\ S^- = \max_i S_i;\ R^* = \min_i R_i;\ R^- = \max_i R_i \tag{1}$$

The parameter v is known as the "maximum group utility," while $1 - v$ represents the "individual regret." The parameter v is determined as follows:

- If $v > 0.5$, the group agreement is too high;
- If $v < 0.5$, the group agreement is low;
- If $v \approx 0.5$, it indicates the consensus in the group.

Step 7- Categorization of the alternatives: the alternatives are sorted ascendant based on S, R, and Q values.

Step 8- The alternatives ranking: The alternative $A^{(1)}$, which has the best (lowest) Q value, is considered the best alternative if the following conditions are met:

Condition 1- "Acceptable advantage": This condition is satisfied when Equation 24 holds, where $A^{(2)}$ is the second-best alternative in terms of Q, and m is the number of alternatives.

$$Q(A^{(2)}) - Q(A^{(1)}) \geq 1/(m - 1) \tag{24}$$

Condition 2- "Acceptable stability in decision making": Alternative $A^{(1)}$ should also rank highest in S or/and R.

If one of the conditions is not met, the best alternative is selected as follows:

- If condition 1 is met, but condition 2 is not, both $A^{(1)}$ and $A^{(2)}$ are selected as the best alternatives.
- If condition 1 is not met, alternatives $A^{(1)}, to, A^{(\mathrm{m})}$ are selected based on the highest value in Equation 25.

$$Q(A^{(\mathrm{M})}) - Q(A^{(1)}) < 1/(m - 1) \tag{25}$$

4. Results

After reviewing the VE models, the evaluation criteria were first determined for their prioritization, followed by ranking the models. The evaluation criteria were similar to those considered by the research of Asgari [10]. This article introduces evaluation criteria to select the most appropriate VE method for different projects. These criteria are designed to assess the strengths and weaknesses of various VE techniques and determine their suitability based on specific project requirements. The framework includes factors such as cost-effectiveness, performance improvement, ease of implementation, and alignment with project goals. Subsequently, these criteria were modified based on the needs of the studied plant, as described in Table 5.

Table 5. Evaluation criteria for VE standards

Indicators	Criteria
C1	Comprehensiveness of the model
C2	Usability for iron and steel industry projects
C3	Simplicity of using the model
C4	Determination of evaluation criteria
C5	Ability to rank and prioritize ideas
C6	Determination of the scope and horizon of the project

For weighting the evaluation criteria according to Table 3 and Formulation 1 and 2, pairwise comparisons were conducted by an expert in VE (manager of industrial engineering and development of iron and steel company) from the studied plant (Table 6 and Table 7) to express the preference between criteria.

Table 6. Pairwise comparisons of evaluation criteria

Criteria	Preferences scores										Criteria
	9	7	5	3	1	3	5	6	7	9	
C1					*						C2
C1		*									C3
C1					*						C4
C1					*						C5
C1				*							C6
C2				*							C3
C2								*			C4
C2								*			C5
C2				*							C6
C3							*				C4
C3									*		C5
C3		*									C6
C4					*						C5
C4		*									C6
C5		*									C6

Table 7. Pairwise comparisons matrix of VE alternatives

Criteria	C1	C2	C3	C4	C5	C6
C1	1	1	7	1	1	3
C2	1	1	3	0.17	0.17	3
C3	0.14	0.33	1	0.2	0.14	3
C4	1	6	5	1	1	7
C5	1	6	7	1	1	7
C6	0.33	0.33	0.33	0.14	0.14	1

This table illustrates how each criterion is preferred over another. For instance, Criterion C1 (Comprehensiveness of the model) has equal preference with Criterion C2 (Usability for iron and steel industry projects) and is highly desirable compared to Criterion C3 (Simplicity of using the model). Then, to calculate the weight of the criteria, pairwise comparisons were entered in the ExpertChoice11 software, the results of which are shown in Figure 1. The *IR* was also less than 0.1.

The ExpertChoice11 software calculates the weight of evaluation criteria using the AHP method as stated in Section 3, which involves several systematic steps. First, it defines the evaluation criteria and constructs a pairwise comparison matrix where each criterion is compared against every other criterion based on their relative importance. The software then computes the Consistency Index (CI) and Consistency Ratio (CR) to ensure logical consistency in these comparisons. Following this, it calculates the eigenvalues and eigenvectors from the pairwise comparison matrix, with the eigenvector representing the relative weights of each criterion. These weights are then normalized to sum up to 1.

Sensitivity analysis is subsequently performed to evaluate how variations in the input judgments influence the final weights of the criteria. This involves adjusting the pairwise comparisons slightly to observe whether the ranking or the relative importance of the criteria remains stable. If minor changes in inputs cause only slight or no changes in the output, it indicates that the model is robust and that the decision-making process is not overly sensitive to subjective judgments.

This process is reliable due to the incorporation of expert judgment, mathematical rigor, consistency checks, and a detailed sensitivity analysis, making the results robust and defensible.

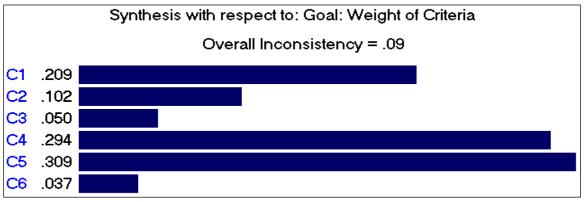

Figure 1. Weight of evaluation criteria

Finally, the VIKOR method is employed for ranking the alternatives. Alternatives are the VE models as explained in Section 2.1 (Table 7).

Considering the steps of the VIKOR method and the weight of evaluation criteria, the scoring of alternatives was initially performed by a VE expert according to

Table 9. Subsequently, prioritization was carried out using Excel software.

Table 8. List of VE alternatives considered

Indicators	Criteria
A1	Lawrence D. Miles

Indicators	Criteria
A2	SAVE Standard
A3	ASTM Standard
A4	European Standard
A5	Australian Standard

According to the steps of the VIKOR method, the alternatives were ranked as follows:

- According to step 2, the $\boldsymbol{N_D}$ matrix is obtained (Table 10).
- According to step 3, the $\boldsymbol{F}$ matrix is obtained (Table 11).
- According to step 4, f* and f- values are obtained (Table 12).
- According to step 5, the value of $w_j \times (f_j^* - f_{ij})/(f_j^* - f_j^-)$ is calculated for each criterion (Table 13).
- According to Table 12, step 5, and step 6, the values of S_i, R_i, and, Q_i were obtained (Table 13).
- According to step 8, the best alternative has a lower Q.
- Table 14 examines conditions (1) and (2).

Table 9. ***D*** **matrix**

Alternatives	Criteria					
	C1	C2	C3	C4	C5	C6
A1	5	3	7	1	3	1
A2	8	8	6	5	7	7
A3	7	6	6	5	7	4
A4	7	5	6	7	5	6
A5	7	7	5	7	4	9

Table 10. $\boldsymbol{N_D}$ **matrix**

Alternatives	Criteria					
	C1	C2	C3	C4	C5	C6
A1	0.325	0.222	0.519	0.082	0.247	0.074
A2	0.521	0.591	0.445	0.410	0.575	0.517
A3	0.456	0.444	0.445	0.410	0.575	0.296
A4	0.456	0.370	0.445	0.573	0.411	0.444
A5	0.456	0.517	0.371	0.573	0.329	0.665

Table 11. ***F*** **matrix**

Alternatives	Criteria					
	C1	C2	C3	C4	C5	C6
A1	0.068	0.023	0.026	0.024	0.076	0.003
A2	0.109	0.060	0.022	0.120	0.178	0.019
A3	0.095	0.045	0.022	0.120	0.178	0.011
A4	0.095	0.038	0.022	0.169	0.127	0.016
A5	0.095	0.053	0.019	0.169	0.102	0.025

Table 12. **f* and f- values**

Ideal values	Criteria					
	C1	C2	C3	C4	C5	C6
f*	0.109	0.060	0.026	0.169	0.178	0.025
f-	0.068	0.023	0.019	0.024	0.076	0.003

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Based on the VIKOR results, the ranking of alternatives is as follows:

1. A2: SAVE Standard
2. A3: ASTM Standard
3. A4: European Standard
4. A5: Australian Standard
5. A1: Lawrence D. Miles

A2 holds the top rank, but it does not satisfy condition 1. Therefore, Step 9 is checked according to the Q values in Table 14 and

.

$$Q(A^{(2)}) - Q(A^{(1)}) = 0.076 < \frac{1}{(4-1)} = 0.25$$

$$Q(A^{(3)}) - Q(A^{(1)}) = 0.251 < \frac{1}{(4-1)} = 0.25$$

$$Q(A^{(M)}) - Q(A^{(1)}) = 0.463 > \frac{1}{(4-1)} = 0.25$$

$$Q(A^{(M)}) - Q(A^{(1)}) = 1 > \frac{1}{(4-1)} = 0.25$$

Table 13. Calculated S_i values for VE alternatives

i	Criteria					
	C1	C2	C3	C4	C5	C6
1	0.209	0.102	0.000	0.294	0.309	0.037
2	0.000	0.000	0.025	0.098	0.000	0.009
3	0.070	0.041	0.025	0.098	0.000	0.023
4	0.070	0.061	0.025	0.000	0.155	0.014
5	0.070	0.020	0.050	0.000	0.232	0.000

Table 14. Calculated S, R and Q values for VE alternatives

Alternatives	S	R	Q	VIKOR indicators
A1	0.951	0.309	1.000	V=0.5
A2	0.132	0.098	0.000	S*=0.132
A3	0.257	0.098	0.076	S-=0.951
A4	0.324	0.155	0.251	R*=0.098
A5	0.372	0.232	0.463	R-=0.309

According to the results, A3 (ASTM Standard) also secures the first position.

The application of the VIKOR method yielded alternative weights with closely aligned values, indicating minimal differences in the performance of the evaluated options. This outcome suggests that the alternatives possess a high degree of similarity in their ability to meet the specified criteria. Such findings are particularly common when the number of alternatives is small, as subtle variations in performance may be less discernible. This scenario underscores the need for a more nuanced analysis to accurately differentiate between the alternatives.

To address this challenge, complementary techniques such as sensitivity analysis or expert judgment can be employed. Sensitivity analysis allows for the examination of how variations in input data affect the results, providing deeper insights into the robustness of the ranking. Additionally, incorporating expert judgment can offer valuable qualitative perspectives that enhance the decision-making process. By combining these approaches, the final ranking can be refined, ensuring that the most suitable alternative is effectively identified and justified.

Table 15. Final ranking of VE alternatives

Alternatives	(QAi-QA1)	(QAi-QA2)	(QAi-QA3)	(QAi-QA4)	(QAi-QA5)	Condition 1	Condition 2
A1	-	1.000	0.924	0.749	0.537	TRUE	TRUE
A2	FALSE	-	FALSE	FALSE	FALSE	FALSE	TRUE
A3	FALSE	0.076	-	FALSE	FALSE	FALSE	TRUE
A4	FALSE	0.251	0.175	-	FALSE	FALSE	TRUE
A5	FALSE	0.436	0.387	0.212	-	TRUE	TRUE

In the mining industry, standards like the ASTM Standard (American Society for Testing and Materials) and the SAVE Standard (Society of American Value Engineers) play crucial roles in ensuring optimal performance and cost-efficiency. The ASTM Standard is well-regarded for its comprehensive guidelines and specifications, covering various aspects such as geospatial data, coal classification, and material testing methods. This standard is designed to enhance safety, quality, and efficiency in mining operations,

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making it a top choice for resource optimization and improved project performance.

On the other hand, the SAVE Standard emphasizes VE principles, focusing on systematic and organized approaches to enhance the value of products and services. By examining functions and identifying ways to achieve desired performance at the lowest cost, the SAVE Standard helps mining projects achieve better resource utilization and cost savings. Its approach to project optimization is highly effective, making it a valuable tool for enhancing overall project efficiency.

When the article highlights that both the ASTM and SAVE Standards secure top positions, it signifies the high regard for these standards in the mining industry. Adopting these standards can lead to significant benefits, including improved safety measures, cost-efficiency, and overall project optimization. By leveraging the strengths of both standards, mining projects can achieve superior performance and value.

5. Conclusion

The objective of this investigation was to conduct a comprehensive review of VE models documented within established standards and prior research endeavours, prioritizing these standards based on their suitability for an iron and steel company. Management tools such as VE empower industrial organizations to resolve challenges without inadvertently generating new ones. This research began by outlining the challenges facing the mining industry and explaining why VE could be a potential solution.

A meticulous examination of VE models revealed that the SAVE standard is the most frequently referenced in the literature. While other standards possess positive attributes and incorporate diverse evaluation criteria, they have received comparatively less scholarly attention. The research methodology employed AHP to determine the relative weights assigned to evaluation criteria, identifying "ability to rank and prioritize ideas" and "determination of evaluation criteria" as the most critical attributes for the iron and steel company. The VIKOR method was then used to prioritize the VE standards, revealing that the SAVE and ASTM standards secured the top rankings.

This result indicates that these two standards offer a more structured, transparent, and comprehensive approach to VE, aligning well with the strategic needs of the iron and steel sector. Specifically, the SAVE standard's emphasis on function analysis and systematic evaluation strongly resonated with the industry's need for cost-effective, high-quality solutions. Likewise, the ASTM standard demonstrated strong alignment due to its structured documentation processes and emphasis on cross-disciplinary collaboration, which is crucial for large-scale industrial projects.

The findings from this research underscore the value of VE in enhancing decision-making within the iron and steel industry. The SAVE and ASTM standards emerged as the top-ranked standards, reflecting their suitability for addressing the specific needs of this sector. These rankings were supported by high scores in key criteria such as clarity of methodology, ease of implementation, and relevance to complex industrial operations. For instance, both standards scored significantly higher in the "usability" and "practical applicability" categories, which are essential for implementation in high-stakes environments like steel manufacturing. The study phase's job plans across various models showed general uniformity, with minor discrepancies observed in the pre-study stage.

The comparative analysis of job plans revealed that most models converge during the functional and evaluation phases, but the pre-study stage varies, often lacking detailed guidance. This highlights an area for improvement, as inadequate preparation at this stage can affect the outcome of the entire VE process. A well-developed pre-study phase ensures alignment between project goals and stakeholder expectations from the outset, thereby enhancing the overall effectiveness of the VE exercise.

This finding highlights the importance of a consistent approach across VE models, with the pre-study phase requiring further refinement to ensure alignment with industry-specific challenges. Additionally, the research emphasized the importance of criteria relevant to the iron and steel company, particularly focusing on cost reductions, quality improvements, and efficient project execution. These findings reinforce the notion that VE models, when properly adapted, have significant potential to optimize industrial processes and drive both financial and operational benefits.

In particular, cost-related criteria were found to have the greatest influence on the final rankings, followed closely by criteria related to idea prioritization and simplicity of model use. This suggests that iron and steel companies are likely to benefit most from VE standards that not only support cost-cutting but also enable quick and effective decision-making. Furthermore, the high weighting of "evaluation criteria determination" reflects the industry's demand for flexible yet structured assessment tools that can be tailored to dynamic project requirements.

From a managerial perspective, adopting VE models, particularly the SAVE and ASTM standards, can provide a strategic advantage by fostering continuous improvement and innovation. By integrating these VE standards, managers can enhance decision-making processes, optimize resource allocation, and engage stakeholders more effectively. Furthermore, these models offer a structured approach to prioritizing initiatives that align with organizational goals, which can drive operational efficiency and improve the company’s competitive position in the market. Managers can leverage these VE frameworks to streamline processes and create a more sustainable, results-driven approach to project execution.

Despite these promising findings, the research faced several limitations. Firstly, the study relied on existing literature, which may not encompass all pertinent VE standards and models. As such, future research could explore underrepresented VE models, potentially broadening the scope and applicability of findings in this field. Secondly, the criteria used for evaluating VE standards were based on expert opinions, which can introduce subjective bias. To mitigate this, future studies could employ a more diverse set of perspectives or use empirical data from real-world applications to provide a more balanced evaluation. Lastly, the generalizability of the findings is constrained by the specific context of the iron and steel company. While this research provides valuable insights for the industry, further exploration of VE applications in other sectors could enhance its relevance and demonstrate broader applicability.

In conclusion, future research should focus on exploring the integration of various VE models to develop a more comprehensive methodology tailored to the unique challenges faced by different industries. Additionally, refining and expanding the evaluation criteria used in this study represents a promising avenue for future studies, as this could lead to more accurate assessments of VE models' effectiveness across diverse industrial contexts. Expanding the research to include real-world case studies and industry-specific applications would also be valuable in validating the findings and enhancing the applicability of VE models in practice.

6. Statements & Declarations

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6.2. Declaration of Interest

The authors declare that there are no conflicts of interest related to the research presented in this article. This research was conducted independently and without any influence from external financial sources or personal relationships.

6.3. Author Contributions

Amirreza Torabi: Conducted the research, gathered data, and prepared the initial draft of the manuscript.

Seyed Hamed Moosavirad: Provided overall guidance and supervision throughout the research process.

Shahram Ariafar: Served as advisory mentors, provided minor oversight, and collaborated on final revisions.

Alireza Eftekhari: Served as advisory mentors, provided minor oversight, and collaborated on final revisions.

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